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Claudia Kemfert*

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*S.P.E.E.D (Scientific Pool of Environmental Economic Disciplines), Dept. of Economics I , University of Oldenburg

Fondazione Eni Enrico Mattei
Corso Magenta, 63, 20123 Milano, tel. +39/02/52036934 – fax +39/02/52036946
E-mail: letter@feem.it
C.F. 97080600154

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–THE MODEL WIAGEM-

Claudia Kemfert

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* Claudia Kemfert is head of section "S.P.E.E.D" (Scientific Pool of Environmental Economic Disciplines) at the Dept. of Economic I , University of Oldenburg.

Address for correspondence:

Dept. of Economic I, Oldenburg University

D- 26111 Oldenburg

E- mail: kemfert@uni-oldenburg.de

Tel: +49 441 798 4106

Fax: +49 441 798 4101

Abstract

This paper presents an integrated economy-energy-climate model WIAGEM (**W**orld **I**ntegrated **A**ssessment **G**eneral **E**quilibrium **M**odel) which incorporates economic, energetic and climatic modules in an integrated assessment approach. In order to evaluate market and non –market costs and benefits of climate change WIAGEM combines an economic approach with a special focus on the international energy market and integrates climate interrelations by temperature changes and sea level variations. WIAGEM bases on 25 world regions which are aggregated to 11 trading regions and 14 sectors within each region. The representation of the economic relations is based on an intertemporal general equilibrium approach and contains the international markets for oil, coal and gas. The model incorporates all greenhouse gases (GHG) which influence the potential global temperature, the sea level variation and the assessed probable impacts in terms of costs and benefits of climate change. Market and non market damages are evaluated due to the damage costs approaches of Tol (2001). Additionally, this model includes net changes in GHG emissions from sources and removals by sinks resulting from land use change and forest activities. This paper describes the model structure in detail and outlines some general results, especially the impacts of climate change. As a result, climate change impacts do matter within the next 50 years, developing regions face high economic losses in terms of welfare and GDP losses. The inclusion of sinks and other GHG changes results significantly.

Key words: Integrated Assessment Modelling, Kyoto mechanisms
JEL classification: D 58, C 68, Q40

Non Technical Abstract

Nearly all scientific reports including the youngest IPCC report confirm once more that the impact of humankind on the natural environment has never been greater (IPCC 2001) and cause substantial long term and irreversible climatic changes. One important source of climate change are the anthropogenic greenhouse gases emissions. Increasing atmospheric concentrations of greenhouse gases have a substantial impact on the global temperature and sea level which generate extensive economic, ecological and climatic impacts. These impacts are investigated by a world integrated assessment modelling tool which combines a detailed description of the main economic relations with a very simplified model to represent the climate interlinkages. Model results confirm the investigations by natural scientists: climate change do matter within the next 50 years and induce substantial impacts to all world regions.

Introduction

Nearly all scientific reports including the youngest IPCC report confirm once more that the impact of humankind on the natural environment has never been greater (IPCC 2001) and cause substantial long term and irreversible climatic changes. One important source of climate change are the anthropogenic greenhouse gases emissions. Increasing atmospheric concentrations of greenhouse gases have a substantial impact on the global temperature and sea level which generate extensive economic, ecological and climatic impacts. Potential impacts of climate change encompass a general reduction in crop yields in most tropical and sub tropical regions, decreased water availability in water- scarce regions, an expansion in the number of people exposed to vector and water borne diseases and heat stress, intensification in the risk of flooding from heavy precipitation events and sea level rise, augmented energy demand for space cooling due to higher summer temperature; beneficial impacts cover an increased potential crop yield in some regions at higher latitude, potential rise in global timber supply from appropriately managed forests, increased water availability, reduced winter mortality and reduced energy demand for space heating due to higher winter temperatures (IPCC 2001). Additionally, working group I of the IPCC reports that the global average surface temperature has risen by 0.6 ± 0.2 °C over the 20th century stressing the fact that the increase in temperature in the Northern Hemisphere have been the largest of any century during the past 1,000 years, 1990 was the warmest decade and 1998 the warmest year. Furthermore, the atmospheric concentration of the greenhouse gases carbon dioxide CO2, methane CH4 and nitrous oxide N2O increased drastically since 1750.

A comprehensive analysis of all previously described effects caused by climate change need to be based on a broad and integrated evaluation tool which combines economic, energy and climate relations in one modelling instrument and so allows an integrated assessment of costs and benefits of emissions reduction policies. Models based on only economic, ecologic or climate considerations allow a comprehensive assessment of only one aspect of climate change. Current models that try to integrate climate interrelations in an economic framework typically use stylised and reduced interrelations of all domains.

This paper presents a novel integrated assessment modelling approach which is based on a detailed account of economic relations. The core is an intertemporal general equilibrium model WIAGEM, including all world regions and the main economic sectors. The general equilibrium models also includes by a representation of the international energy markets for oil, coal and gas. The economic model is coupled to a model of the ocean carbon cycle and climate.

WIAGEM has 25 world regions which are aggregated to 11 trading regions and 14 sectors within each region. The model incorporates the greenhouse gases (GHG) CO2, CH4 and N2O, which affect the global temperature, the sea level. In turn, temperature and sea level determine the impacts of climate change. Market and non market damages are evaluated due to the damage costs approaches of Tol (2001). Additionally, this model includes net changes in GHG emissions from sources and removals by sinks resulting from land use change and forest activities.

The first part of this paper gives a brief overview of existing economic, climatic and ecosystem-models and integrated assessment approaches. The main focus of this paper is the description of the integrated assessment model WIAGEM. Primarily, the economic, energy and the climatic module of the model are explained thoroughly. The paper concludes by a short illustration of selected key model results.

Integrated Assessment models

The economic assessment of climate change is based on either pure economic models focusing on economic relations and interlinkages or economic models enlarged by stylised climatic interrelations or submodels which are usually known as integrated assessment (IAM) models. Ecological effects like impacts of climate change on biodiversity are mainly modelled by ecosystem models concentrating on ecological interrealtions (see Prentice et al., 1992, Haxeltine et al., 1996, Kaplan 2001, Esser et al. 1994, Kaduk 1996 Knorr, 2000, Knorr und Heimann, 2001); climatic impacts can be assessed chiefly by sophisticated climate models (Maier-Reimer & Hasselmann 1987, Maier-Reimer 1993, Sarmiento & al 1992, Siegenthaler 1978, Hasselmann & al. 1997, Joos & al 1999, Hooss 2001). Pure economic models base primarily on a general equilibrium approach based on aggregated world regions which mostly do not include sectoral disaggregation. Economic model that include sectoral disaggregation of world regions by a general equilibrium model do mainly not embrace ecological or climatic interrelations. Economic effects by emissions reduction policies are investigated by Bernstein und Montgomery (1999), McKibbin and Wilcoxen (1999), Böhringer and Rutherford (1998) and Kemfert (2000).

Costs and benefits of climate change are predominantly assessed by integrated assessment models (IAM) incorporating physical relations of climate change and economic effects by damage functions. Examples for IAMs are MERGE (Manne and Richels 1998), RICE or

DICE (Nordhaus and Yang 1998), CETA (Peck und Teisberg 1991) or FUND (Tol 1998). In contrast, these models do not include sectoral disaggregation of each world region.

Edmonds (1998) gives an overview of newest modelling approaches, previous overviews can be found in Dowlatabadi (1993), Dowlatabadi, and Rotmans (1998) and Toth (1995). Integrated assessment models are characterised by combining multidisciplinary approaches in order to evaluate impacts by climate change thoroughly. The model presemted in this paper WIAGEM tries to integrate in a first step a detailed economic model including all world regions and sectoral disaggregation with an energy and climate submodel. The model includes all greenhouse gases and potential net emissions changes due to sink potential from land use change and forestry. The climatic model bases on general interrelations between energy and non energy related emissions, temperature changes and sea level variations which all induce substantial economic impacts in terms of market and non market damage costs.

The Model WIAGEM

WIAGEM is an integrated assessment model which combines an economy model based on a dynamic intertemporal general equilibrium approach combined with an energy market model and a climatic submodel covering a time horizon of 50 years solving for five years time steps.[1] The basic idea behind this modelling approach is the evaluation of market and non market impacts induced by climate change. The economy is represented by 25 world regions which are aggregated to 11 trading regions, each region covers 14 sectors. The sectoral disaggregation contains five energy sectors: coal, natural gas, crude oil, petroleum and coal products and electricity. The dynamic international competitive energy market for oil, coal and gas is modelled by global and regional supply and demand, the oil market is characterised by imperfect competition with the intention that the OPEC regions can use their market power to influence market prices. Energy related greenhouse emissions occur as a result of economic and energy consumption and production activities. At the present time, a number of gases have been identified as having a positive effect on radiative forcing (IPCC 1996) which are included in the Kyoto protocol as “basket” of greenhouse gases. The model includes three of these gases: carbon dioxide (CO2), methane (CH4) and nitrous dioxide (N2O) which are evaluated to be the most influential greenhouse gases within the short term modelling period of 50 years. The exclusion of the other gases is not believed to have substantial impacts on the insights of the analysis.

Because of the short term application of the climate submodel, we consider only the first atmospheric lifetime of the greenhouse gases, assuming that the remaining emissions have an infinite life time. The atmospheric concentrations induced by energy related and non energy related emissions of CO2, CH4 and N2O have impacts on radiative forcing which influence the potential and actual surface temperature and sea level. Market and non market damages determine the regional and overall welfare development.

[1] The model is written in the computer language GAMS (MPSGE) and solved by the algorithm MILES, see Rutherford (1993)

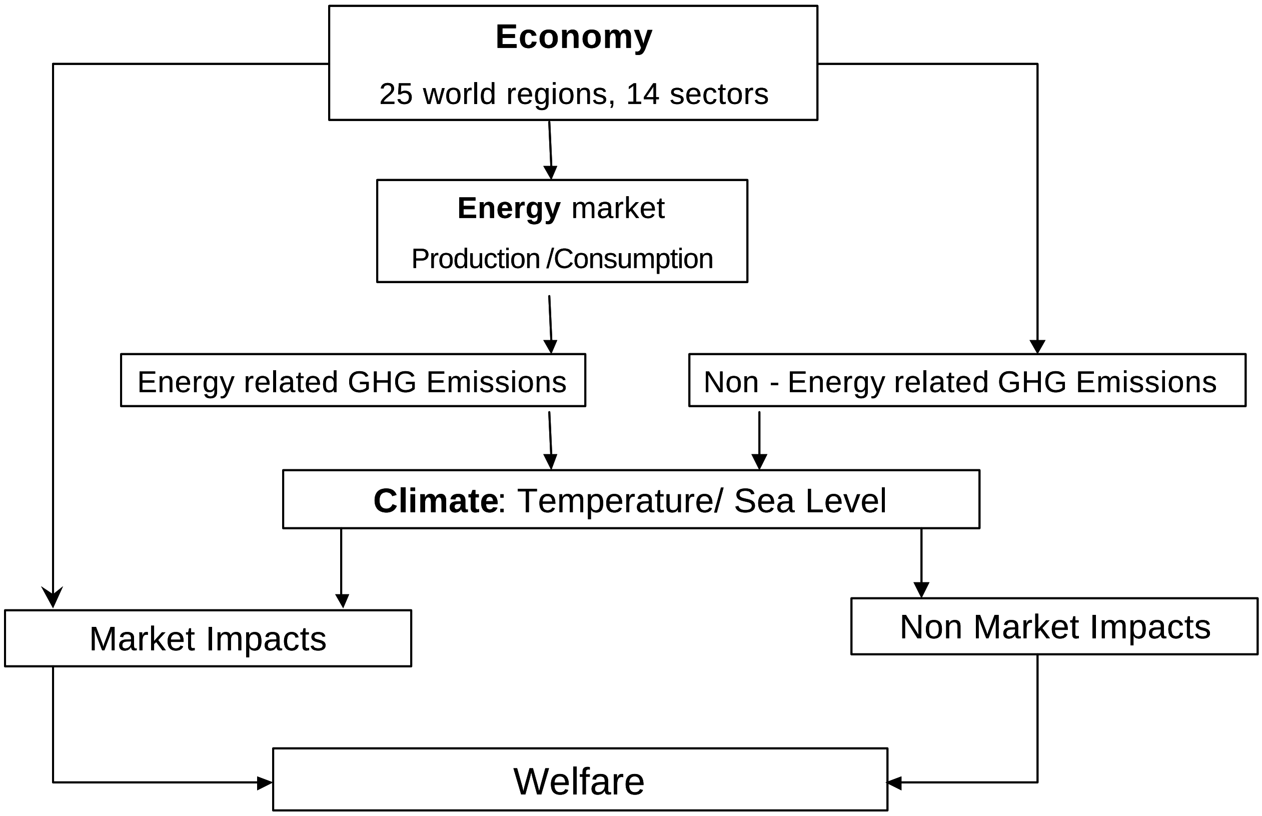

Figure 1: Interrelations in WIAGEM

Economy

The economy is represented by an intertemporal computable general equilibrium and multi regional trade model covering 25 world regions aggregated to 11 trading regions which are linked through bilateral sectoral trade flows. The model base on GTAP 4.0 data[2] of 1995. The world regions are aggregated to the following 11 trading regions:

[2] See McDOUGALL, R.A. (1995)

	Regions
ASIA	India and other Asia (Republic of Korea, Indonesia, Malaysia, Philippines, Singapore, Thailand, China, Hong Kong, Taiwan)
CHN	China
CNA	Canada, New Zealand and Australia
EU15	European Union
JPN	Japan
LSA	Latin America (Mexico, Argentina, Brazil, Chile, Rest of Latin America)
MIDE	Middle East and North Africa
REC	Russia , Eastern and Central European Countries
ROW	Other countries
SSA	Sub Saharan Africa
USA	United States of America

Table 1: World regions

The economic structure of each region consists of five energy sectors: (1) coal, (2) natural gas, (3) crude oil, (4) petroleum and coal products and (5) electricity and industrial sectors, agriculture and services. Because of the intertemporal optimisation framework we explicitly include a savings good sector. The aggregated factors for production include land, labour and capital.

All products are demanded by intermediate production, exports, investment and a representative consumer, market actors behave within a full competition context. Consumption and investment decisions are based on rational point expectations of future prices. The representative agent for each region maximises lifetime utility from consumption which implicitly determines the level of savings. Firms choose investment in order to maximise the present value of their companies.

	Sectors
COL	Coal
CRU	Crude Oil
GAS	Natural Gas
EGW	Electricity
OIL	Petroleum and coal products
ORE	Iron and Steel
CRP	Chemical Rubber and Plastics
NFM	Non Ferrous Metals
NMM	Non Metal mineral Products
AGR	Agriculture
PPP	Pulp and Paper
TRN	Transport industries
Y	Other manufactures and Services
CSG	Savings good

Table 2: Sectoral classification

In each region production of the non-energy macro good is captured by an aggregate production function which characterises technology through transformation possibilities on the output side and substitution possibilities on the input side between alternative combinations of inputs. Goods are produced for the domestic and for the export market. Production of the energy aggregate is described by a CES function which reflects substitution possibilities for different fossil fuels (i.e., coal, gas, and oil) and capital, labour representing trade off effects with a constant elasticity of substitution. Fossil fuels are produced from fuel-specific resources and the non-energy macro good subject to a CES technology.

The CES production structure follows the concept of ETA-MACRO combining nested capital and labour at lower level. Energy is treated as a substitute of a capital labour composite determining together with material inputs the overall output (see Figure 2).

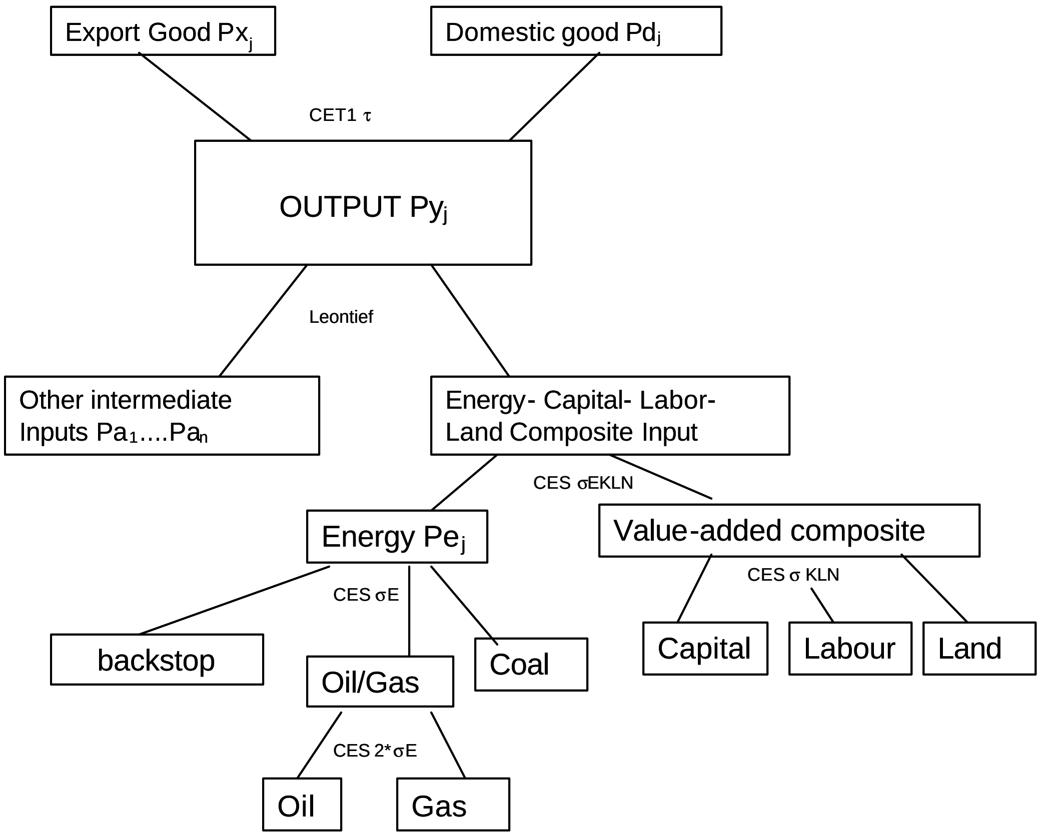

Figure 2: Production Structure of sector j in region r

The representative producer of sector j ascertains the CES *profit function*

$$\Pi_j^Y(p) = \left[a_j^{DX}(p_j^{1-s_{DX}} + (1-a_j^{DX})p^{FX^{1-s_{DX}}}\right]^{\frac{1}{1-s_{DX}}}$$

$$-\left[a_j^M p_j^{M1-s_{KEM}} + (1-a_j^M)\left[a_j^E p_j^{E1-s_{KLE}} + (1-a_j^E)\left[a_j^K(p^{RK})^{1-s_{KL}} + (1-a_j^K)(p_j^L)^{1-s_{KL}}\right]^{\frac{1-s_{KLE}}{1-s_{KL}}}\right]^{\frac{1-s_{KLEM}}{1-s_{KLKE}}}\right]^{\frac{1}{1-s_{KLEM}}} \qquad (1.1)$$

with:

a_j^{DM} : Domestic production share of total production by sector j

a_j^K : Value share of capital within capital –energy composite

a_j^L : Value share of labour within capital -energy -labour aggregate

a_j^M : Value share of material within capital-energy-labour material aggregate

p_j : Price of domestic good j

p^{FX}: Price of foreign exchange (exchange rate)

p^{RK}: Price of capital

p_j^E : Price of energy

p_j^M : Price of material/land

p^L: Price of labour

s_{KE}: Substitution elasticity between capital and energy

s_{KEL}: Substitution elasticity between labour and capital and energy composite

s_{KLEM}: Substitution elasticity between material and labour/ capital and energy- composite

Y: Activity level of production sector j.

CET: Constant elasticity of transformation τ

CES: Constant elasticity of substitution σ

A representative agent for each region maximises its region's discounted utility over the model's time horizon (50 years) under budget constraint equating the present value of consumption demand to the present value of wage income, the value of initial capital stock, the present value of rents on fossil energy production and tax revenue. In each period households face the choice between current consumption and future consumption, which can be purchased via savings. The trade-off between current consumption and savings is given by a constant intertemporal elasticity of substitution. Producers invest as long as the marginal return on investment equals the marginal cost of capital formation. The rates of return are determined by an uniform and endogenous world interest rate such that the marginal productivity of a unit of investment and a unit of consumption is equalised within and across countries. The primary factors, capital, labor, and energy are combined to produce output in period t. In addition, some energy is delivered directly to final consumption. Output is separated in consumption and investment, investment enhances the (depreciated) capital stock of the next period. Capital, labor, and the energy resource earn incomes, which are either spent on consumption or saved. Saving equals investment through the usual identity (see Figure 3). Protection costs lower other investment in the economy (crowding out).

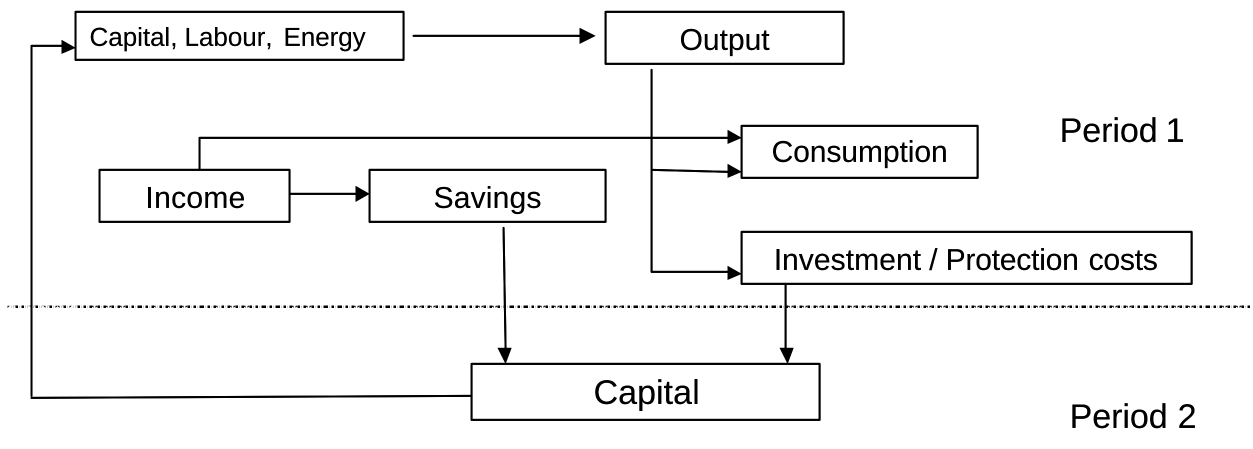

Figure 3: Dynamic structure

Capital is used for production with a capital price p_t^K and an utility price of p_t^{RK} and is depreciated by rate δ:

$$\Pi_t^K(p) = (1-d)\, p_{t+1}^K + p_t^{RK} - p_t^K - ptc_t^r \tag{1.2}$$

with:

p_t^K : Price of capital in period t

p_t^{RK} : Price of capital services in period t

K_t: Activity level of capital in period t

ptc_t^r : regional protection costs

Investments are produced by Leontief technology:

$$\Pi_{t+1}^I(p) = P \quad p_{t+1}^K - \sum_j a_j^I p_{j,t}^A \tag{1.3}$$

a_j^I Value share investment of good j

I_t: Activity level of investments in period t

P: Time period

Labour is supplied by household and demanded by firms, all household are confronted with a specific time quota be spend for labour or leisure. This labour – leisure decision is determined by net wages ensuring a price elastic labour supply. One representative agent by each region demands a composite consumption good produced by combining the Armington good and the household energy aggregate good according to a CES configuration. σ_{end} describes the elasticity of substitution between the composite macro good and the energy aggregate. Aggregate end-use energy is composed of oil, gas, and coal with an interfuel elasticity of substitution equal to one. The backstop fuel is a perfect substitute for the energy aggregate.

Purchase of the good is financed from the value of the household's endowments of labor, capital, energy specific resources, and revenue from any carbon tax or permit prices, respectively (see Figure 4).

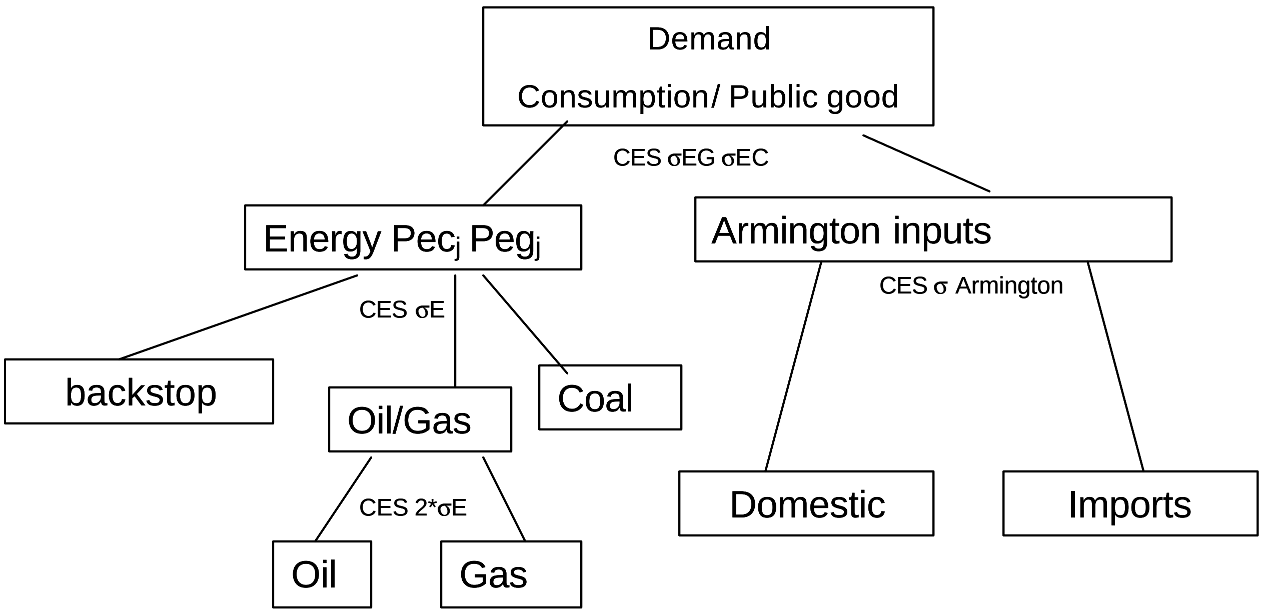

Figure 4: Final Demand Structure

Mathematically, this dependence can be written:

$$\Pi^{CG}(p) = p^{CG} - \left[a_E^{CG} (p_E^{HH})^{1-s_C} + \sum_i a_i^{CG} (p_i^A)^{1-s_C} \right]^{\frac{1}{1-s_c}} \quad (1.4)$$

with:

p^{CG}: Price of consumption good

a_E^{CG} : Value share of energy aggregate in final demand

a_i^{CG} : Value share of non- energy good in final demand

CG: Activity level of real consumption good production

Domestic and imported varieties for the non-energy good for all buyers in the domestic market are treated as incomplete substitutes by a CES Armington aggregation function providing a constant elasticity of substitution. With respect to trade in energy, fossil fuels are treated as perfect substitutes, net trade cannot be cross-moved. International capital flows reflect borrowing and lending at the world interest rate, and are endogenous subject to an intertemporal balance of payments constraint considering no changes in net indebtedness over the entire model horizon.

The profit function by *Armington production* is specified by:

$$\Pi_j^A(p) = p_j^A - \left[a_j^A p_j^{A\,1-s_{DM}} + (1-a_j^A)\left(p^{FX}\right)^{1-s_{DM}}\right]^{\frac{1}{1-s_{DM}}} \qquad (1.5)$$

with:

p_j^A: Price of Armington good j

a_j^A: Domestically produced good j value share of domestic and import good aggregate

p^{FX}: Price of foreign exchange (exchange rate)

s_{DM}: Substitution elasticity between domestically and imported good

A_j: Armington activity level

Energy

WIAGEM includes four energy production sectors, one non-energy sector and three fossil fuel sectors traded internationally for oil, gas and coal. Coal production in the OECD and gas production in Russia grow with energy demand at constant prices. The elasticity of substitution between the resource input and non-energy inputs is calibrated to meet a given price elasticity of supply. Exhaustion leads to rising fossil fuel prices at constant demand quantities. The carbon-free backstop technology establishes an upper bound on the world oil price, this backstop fuel is a perfect substitute for the three fossil fuels and is available in infinite supply at one price, which is calculated to be a multiple of the world oil price in the benchmark year. Demand elasticities depend on back stop technologies, by low backstop costs demand elasticities are high and vice versa.

A composite energy good is produced by either conventional fossil fuels - oil, gas, and coal – represented by a nested CES technology (with an elasticity of interfuel substitution σ_{fuel}) or from a backstop source with Leontief technology structures. Oil and gas can be substituted by an elasticity of substitution twice as large as the elasticity between their aggregate and coal. The energy good production is determined by final demand of industry and households .

$$\begin{aligned}\Pi_j^E(p) = p_j^E - \Big[& a_j^{ELE} p_j^{ELE\,1-s_{ELE}} + (1-a_j^{ELE}) a_j^{OIL} (p_j^{OIL} + ef_j^{OIL,CO2} p^{CO2})^{1-s_{FOSSIL}} \\ & + a_j^{GAS} (p_j^{GAS} + ef_j^{GAS,CO2} p^{CO2})^{1-s_{FOSSIL}} + a_j^{COA} \big[a_j^{HCO} (p_j^{HCO} + ef_j^{HCO,CO2} p^{CO2})^{1-s_{COA}} \\ & + a_j^{SCO} (p_j^{SCO} + ef_j^{SCO,CO2} p^{CO2})^{1-s_{COA}} \big]^{\frac{1-s_{FOSSIL}}{1-s_{COA}}} \Big]^{\frac{1-s_{ELE}}{1-s_{FOSSIL}}} \Big]^{\frac{1}{1-s_{ELE}}}\end{aligned} \qquad (2.1)$$

With:

a_j^{ELE} Electricity value share of energy aggregate by sector j

a_j^{OIL} Oil value share of fossil energy aggregate by sector j

a_j^{GAS} Gas value share of fossil energy aggregate by sector j

a_j^{HCO} Hard coal value share of coal aggregate by sector j

a_j^{SCO} Soft coal value share of coal aggregate by sector j

σ_{ELE} Substitution elasticity between electricity and fossil energy

σ_{FOSSIL} Substitution elasticity between fossil energy inputs

σ_{COA}: Substitution elasticity between hard and soft coal

$ef_j^{OIL,CO2}$ CO_2 share of oil in sector j

$ef_j^{GAS,CO2}$ CO_2 share of gas in sector j

$ef_j^{HCO,CO2}$ CO_2 share of hard coalin sector j

$ef_j^{SCO,CO2}$: CO_2 share of soft coal in sector j

p^{CO2} Price of carbon

E_j Activity level of energy production

Demanded energy by households is produced by a CES function:

$$\Pi_{HH}^{E}(p) = p_{HH}^{E} - \left[\sum_{i=EG} a_{i,HH}^{CO2} (p_i^A + a_i^{CO2} p^{CO2})^{1-s^{EG}} \right]^{\frac{1}{1-s^{EG}}} \qquad (2.2)$$

with:

$a_{i,HH}^{E}$ Value share of energy good i of household

p_{HH}^{E}: Price of energy by household demand

σ_{EG}: Substitution elasticities between energy goods

E_{HH}: Activity level of energy production by household

The intertemporal optimal dynamic allocation is characterised by the steady state growth path which means that in order to reach the equilibrium conditions all sizes have to rise by a same growth rate. In the long run, conventional energy as fossil fuels are typified by exhaustion which increases resource prices. We assume that within the future time periods an carbon free backstop technology will be developed and utilised in order to substitute conventional energy.

Because of that a carbon free backstop technology can be utilised within future times at price f^{BS} \$/t CO_2. Zero profit condition is determined by:

$$\Pi^{BS} = p^{CO2} - p^{CG} f^{BS} \tag{2.3}$$

with:

p^{CG}: Price of consumption good

f^{BS}: Costs of carbon free energy supply

BS: Activity level of backstop technology

Emission limits can be reached by domestic action or by trading emission permits within Annex B countries allocated initially due to regional commitment targets. Those countries meeting the Kyoto emissions reduction target stabilise their mitigated emissions at 2010 level.[3]

According to regional abatement costs countries will sell or buy emission permits. Countries facing high abatement costs above permit prices will purchase emission permits, regions with marginal abatement costs lower than the permit price will vend emission licenses. Revenues from selling permits are refunded lump-sum back to the representative consumer in the abating country. Within this context it has to be stressed that problems around the concrete implementation of the flexible mechanisms and emissions trading scheme, like on compliance, early crediting and deception in order to influence permit prices are neglected within the modelling context.

Climate

The model comprises three of the most important anthropogenic greenhouse gases: carbon dioxide (CO2) which covers over 80 percent of total radiative forcing by anthropogenic greenhouse gases, methane (CH4) and nitrous oxide (N2O). Primarily due to human activities, the concentration of these gases in the earth atmosphere have been increasing since the industrial revolution.

In WIAGEM, we consider the relationship between man made emissions and atmospheric concentrations and the resulting impact on temperature and sea level. Because of the short term analysis of considering 50 years up to 2050, we neglect classes of atmospheric greenhouse gas stocks with different atmospheric lifetimes as modelled usually by the impulse response function and reduced forms of carbon cycle model developed by Maier-Reimer and Hasselmann (1987) and applied by Hooss (2001). Energy and non energy related

[3] This can be called as "Kyoto forever" scenario

atmospheric concentrations of CO2, CH4 and N2O have an impact on radiative forcing relative to their base year levels. Energy related emissions are calculated due to the energy development of each period, energy related CO2 emissions are considered by the emissions coefficients of the EMF group:

	Coal	Oil	Gas
CO2 Coefficients in billion metric tons/ Exaj.	0.2412	0.1374	0.1994

Table 3: CO2 Coefficients

Energy related CH4 emissions are determined by the CH4 emissions coefficients of gas and coal production in billion tons of CH4 per exajoule gas and coal production, the coefficients are taken from the MERGE model 4.0 (Manne 1998).

	USA	EU15	JPN	CNA	FSU	CHN	MIDE	ASIA	ROW
2000	0,187	0,493	0,000	0,225	1,005	1,170	1,377	0,468	0,982
2010	0,168	0,413	0,000	0,222	0,823	0,955	1,121	1,121	0,805
2020	0,149	0,333	0,000	0,190	0,641	0,740	0,864	0,864	0,627
2030	0,131	0,253	0,000	0,158	0,458	0,524	0,607	0,607	0,449
2040	0,112	0,173	0,000	0,126	0,276	0,309	0,350	0,350	0,271
2050	0,094	0,094	0,000	0,094	0,094	0,094	0,094	0,094	0,094

Table 4: Emissions coefficients in billion tons of CH4 per exajoule gas production;

Source: MERGE4.0

	USA	EU15	JPN	CNA	FSU	CHN	MIDE	ASIA	ROW
2000	0,354	0,196	0,000	0,371	0,512	0,963	0,000	0,117	0,356
2010	0,354	0,196	0,000	0,371	0,512	0,963	0,000	0,117	0,356
2020	0,354	0,196	0,000	0,371	0,512	0,963	0,000	0,117	0,356
2030	0,354	0,196	0,000	0,371	0,512	0,963	0,000	0,117	0,356
2040	0,354	0,196	0,000	0,371	0,512	0,963	0,000	0,117	0,356
2050	0,354	0,196	0,000	0,371	0,512	0,963	0,000	0,117	0,356

Table 5: Emissions coefficients in billion tons of CH4 per exajoule coal production

Source: MERGE 4.0.

Non energy related emissions cover parts of the CH4 emissions and N2O emissions. The global carbon dioxide emissions baseline pathway is assumed to start from 6 to 11 billion tons of carbon in 2030 which is roughly consistent with the carbon emissions projections of the IPCC reference case of medium economic growth (IPCC 1996).

	USA	EU15	JPN	CNA	FSU	CHN	MIDE	ASIA	ROW
CH4	25,8	15	1	5	7	43,2	0	46	132
N2O	1,1	0,8	0,1	0,3	0,3	0,7	0,2	0,5	1,7

Table 6: Non energy related emissions in million tons-1990; Source: MERGE 4.0 , IPCC (1994) and IEA (1998)

Additionally, net changes in greenhouse gas emissions are covered from sources and removal by sinks resulting from human induced land use change and forest activities like aforestration, reforestration and deforestration. We use potential sinks enhancements as measured by the IPCC (1996) and used in MERGE 4.0[4]:

	USA	EU15	JPN	CNA	FSU	CHN	MIDE	ASIA	ROW
Sinks 2010	50	17	0	50	34	25	25	13	250

Table 7: Potential sinks enhancement in 2010 in million tons of carbon; Source: MERGE 4.0[5]

Atmospheric concentrations of CO2, CH4 and N2O have impacts on the radiative forcing relative to the base level:

$$\Delta F_{CO2} = 6.3 \ln(\frac{CO2}{CO2_0}) \quad (3.1)$$

$$\Delta F_{CH4} = 0.036\,(CH4^{0.5} - CH4_0^{0.5}) - f(CH4, N2O) + f(CH4_0, N2O_0) \quad (3.2)$$

$$\Delta F_{N2O} = 0.14(N2O^{0.5} - N2 =_0^{0.5}) - f(CH4_0, N2O) + f(CH4_0, N2O_0) \quad (3.3)$$

with ΔF measured in Wm^{-2} as changes in radiative forcing of each greenhouse gas corresponding to a volumetric concentration change for each greenhouse gas relative to the base level. The CH4-N2O interaction term is determined by:

$$f(CH4, N2O) = 0.47 \ln\left[1 + 2.01 \cdot 10^{-5} \cdot (CH4 \cdot N2O)^{0.75} + 5.31 \cdot 10^{-15} \cdot CH4 \cdot (CH4 \cdot N2O)^{1.52}\right] \quad (3.4)$$

Total chances of radiative forcing F is obtained by summing each greenhouse gas radiative forcing effect. The potential temperature PT is influenced by radiative forcing with d as parameter (d= 0.455):

$$\Delta PT = d \cdot \Delta F \quad (3.5)$$

Actual temperature is reached by a time lag because of the lag of potential impacts of climate change due to tempertature changes:

[4] We follow the approach of Manne and Richels and MacCracken (1999) that additional sinks enhencement activities are costless. An assessment of different sink options analyses Missfeld and Haites (2001), a further sinks overview gives Schwarze (1999)

[5] See Manne and Richels (2000)

$$\Delta AT_{t-1} - \Delta AT = tlag \cdot (\Delta PT_t - \Delta AT_t) \tag{3.6}$$

with *tlag* as the time lag, ΔAt_t measures the actual change in temperature in year t relative to the base year.

Because of the short term analysis of approximately 50 years from now,sea level changes will change insignificantly during this time period. However, newest calculation estimate a rough linear relationship between temperature changes and sea leven variations. By assuming that sea level will vary by 7 cm of 1 °C temperatur change (s=7), we calculate small sea level changes due to the actual temperature changes: sea level variations are determined by the very rough estimates of a linear relationship between actual temperature:[6]

$$\Delta SL = s \cdot \Delta AT \tag{3.7}$$

Impacts of climate change cover market and non market damages, the former comprise all sectoral damages, production impacts, loss of welfare etc, the latter contain ecological effects like bioviversity losses, migration, natural disasters etc. In order to assess impacts by climate change we follow the approach of Tol (2001) to cover impacts on forestry, agriculture, water resources and ecosystem changes as an approximation of a linear relationship between temperature changes, per capita income or GDP and protection costs due to sea level rise. Tol (2001) estimates vulnerability of climate change, covering a comprehensive evaluation of diverse climate change impacts. Besides sctoral impacts on agriculture, forestry, water resources and energy consumption he covers impacts on ecosystems and mortality due to vector borne diseases, and cardiovascular and respiratory disorders. We use the assessed protection costs and use an approximation of potential impacts. Impacts are additional costs to the economy lowering other investments (crowding out effect). Protection costs due to sea level rise shows Table 8.

USA	EU15	JPN	CNA	FSU	CHN	ASIA	MIDE
71,38	136	63	10,79	53	171	305	5

Table 8: Protection costs of one metre sea level rise in 10^9 \$; Source: Tol (2001)

Aggregated impacts of climate change are evaluated by:

$$\Delta DAM_t^r = a_t^r \cdot (\Delta PT_t^b \cdot \frac{y_t^r}{y_0^r}) + PC_t^r \tag{3.8}$$

[6] These estimates base on assumptions by the climate model NICCS, Hooss (2001)

with DAM as total impacts (damages), α and β are parameters, PC represents the sectoral protection costs due to sea level rise.

Basic model results

Climate Change impacts

Climate change impacts do matter within the next 50 years, model results demonstrate that primarily developing countries have to accept high welfare losses and GDP reductions in comparison to a scenario where no climate change impacts are included. The CC scenario describes the Climate Change (CC) scenario and is compared against a scenario where no climate impacts are evaluated.

	Welfare	GDP	Impacts in%
JPN	-0,08	-0,02	0,12
CHN	-1,14	-0,57	3,44
USA	-0,28	-0,05	0,30
SSA	-0,82	-0,24	1,45
ROW	-1,29	-0,31	1,87
CNA	-0,23	-0,09	0,54
EU15	-0,24	-0,06	0,36
REC	-0,44	-0,08	0,48
LSA	-0,29	-0,12	0,72
ASIA	-0,3	-0,18	1,09
MIDE	-0,04	-0,1	0,60

Table 9: Welfare in HEV, GDP in % and impacts in % of the CC scenario in comparison to no impact assessment

Developing regions suffer if climate impacts are included because of their vulnerability and also because of higher percentage impacts of economic values. Relatively poor countries have to spend higher percentage of their income on protection costs, as a consequence production losses because of less economic investments are much higher in this regions. Rich countries like USA or Europe suffer by economic losses in terms of welfare as real income losses and in terms of GDP reductions, but percentage decreases are not as significant as in developing regions. As these results demonstrate, climate change impacts do matter even within the next 50 years, primarily developing regions are affected negatively.

Kyoto emissions reduction

This section describes some basic model results. The model horizon encompasses 50 years, the model solves in 5 years time period. By including all greenhouse gases as described in section 2 of this paper, total GHG emissions increase from roughly 9 billion ton to 17 billion ton carbon equivalent emissions in 2050 (IPCC emissions scenarios (1999)), see Figure 7.

Regional greenhouse gas emissions differ substantially, the inclusion of the other greenhouse gases CH4 and N2O raises reference emissions for the European Union from 1.517 in 2010 to 1.894 billion tons of carbon. For the US, the inclusion of sinks lowers the greenhouse gas emissions from 2.133 to 2.030 in 2010 and 2.686 to 2.496 billion tons of carbon in 2050. Japan has no significant net emissions changes due to the inclusion of sinks. The global CO2 emissions baseline pathway is assumed to start from 6 to 12,7 billion tons of carbon in 2050 which is roughly consistent with the carbon emissions projections of the IPCC reference case of medium economic growth (Figure 5 and Figure 6).

The inclusion of sinks lowers total net GHG emissions to roughly 15.5 bil t. carbon equivalent in 2050 (see Figure 7). Because of the time deceleration of response impacts by potential and actual temperature changes range from 0.15 to 0.25 °C from 2030 to 2050, the inclusion of sinks cause comparatively marginal declines of actual temperature after 2030.

Because of the assumed linearity between temperature changes and sea level rise, the potential sea level increase by 1 cm in 2025 to roughly 1.8 cm in 2050. As seen before, the incorporation of sinks by land use change and forestry tends to lower this increase marginally after 2030. These changes are low in comparison to other projected studies (IPCC 2001) and can be explained mainly by the short term time horizon considered and because of the time deceleration of response impacts (Figure 9).

Potential impacts by climate change are measured in percentage of global GDP which cover impacts on forestry, agriculture, water resources and ecosystem changes as an approximation of a linear relationship between temperature changes, per capita income or GDP and protection costs due to sea level rise. Emission reduction augments climate change impacts through warming and sea level rise. Figure 10 compares the impacts of climate change through the emissions reductions induced by the Kyoto protocol. The emissions reductions attempt prescribed by the Kyoto protocol causes hugh economic effort by drastic GHG emissions reductions which induce lower economic impacts of climate change as percentage of GDP. In terms of impacts in percentage of GDP this means that with the inclusion of sinks global impacts increase because of less economic welfare losses. Because of hugh economic efforts that have to be undertaken in order to reach the emissions targets of the Kyoto protocol, regional welfare declines especially for those regions which have high emissions reduction targets (Table 10). By the inclusion of sinks as reduced net emissions impacts in terms of percentage GDP changes increase because of less GHG emissions reduction needs and therefore less income and GDP losses.

Developing regions suffer by the implementation of the Kyoto protocol and emissions reduction targets mainly because of international trade spill over effects. Although we allow international emissions permits trading, economic welfare in terms of the Hicksian equivalent which explains the real income variation decreases in developed and developing regions. This is because trading losses as a result of drastic economic efforts by developed regions cause negative spill over effects. A drastic emissions reduction lowers the demand for energy which induce a energy price diminution. Regions with high energy import shares could benefit by this development but countries that face a high share of energy exports will suffer as for example the coal exporting region China.

	Kyoto ALL GHG	Kyoto CO2	Kyoto GHG trade	Kyoto CO2 trade	sinks
JPN	-0,09	-0,15	-0,05	-0,08	-0,01
CHN	-0,08	-0,14	-0,04	-0,09	-0,06
USA	-0,35	-0,42	*-0,12*	*-0,19*	-0,10
SSA	-0,02	-0,01	-0,03	-0,01	-0,05
ROW	-0,14	-0,18	-0,05	-0,08	-0,01
CNA	-0,08	-0,10	-0,05	-0,07	-0,02
EU15	-0,28	-0,39	*-0,18*	*-0,24*	-0,12
REC	-0,08	-0,12	*0,24*	*0,33*	*0,11*
LSA	-0,02	-0,01	-0,01	-0,01	-0,03
ASIA	-0,12	-0,18	-0,09	-0,11	-0,08
MIDE	-0,13	-0,19	-0,08	-0,10	-0,01

Table 10: Welfare effects measured in Hicksian equivalent in comparison to the base case

If no emissions permit trading is allowed, as one main seller of emissions permits Russia will suffer due to high economic losses. Developed regions like EU15 or Japan face high abatement costs which leads to higher economic losses by meeting the Kyoto emissions reduction target. If all GHG are included, the number of low costs abatement options are increased improving the economic situation for OECD regions. Without the allowance of permit trade, regional welfare impacts are much higher if only CO2 emissions are included.

The negative welfare effect for Russia and Eastern Europe can be explained as follows: the Russian economy is weak and substantial production and trade efforts are necessary in order to regain their economic potential. If the Kyoto protocol is implemented, substantial welfare losses occur to Annex I regions resulting in terms of trade deterioration. In comparison to the BAU case where no emissions reduction measures are active, Russia`s positive export trends of for example selling more gas than before cannot overcompensate negative trade spill over effects coming from economic declines of other strong Annex I countries.

A comparison of a trade versus no trade scenario demonstrates that all countries can benefit by Annex B permit trading, mainly countries in transition as REC because of the "hot air" effect. Emissions permit trading better off all Annex B countries as well as non Annex B or developing countries because of international trade spill over effects. Annex B countries facing high emissions reduction targets and high domestic marginal abatement like Japan and USA costs will certainly benefit by Annex B emissions permit trading. Essentially, USA and EU 15 will trade permits within a full trade scenario because of their high share on total carbon emissions. The option of permit trade lowers negative welfare impacts, the inclusion of all GHG bring about a decreasing international permit price which also leads to more benefits for OECD regions by making imports more attractive relative to domestic emissions abatement.

The inclusion of sinks and the parallel GHG emissions reduction target forced by the Kyoto protocol improves the welfare effects in comparison to the Kyoto emissions reduction scenario without the inclusion of sinks. Especially the oil exporting region OPEC and the USA and also Canada are benefiting by the inclusion of sinks because of less severe emissions reductions targets. It improves also the economic welfare impacts in comparison to the cases where trade is allowed.

Conclusion

The model WIAGEM is an integrated assessment model that build on a detailed economic intertemporal general equilibrium model covering 25 world regions and 14 sectors of each world region. It contains an energy submodel that represents the international market for oil, coal and gas allowing a more realistic representation of the oil market in that sense that the OPEC regions can influence the oil market price due to their market power. An integrated assessment of economic, ecological and climate impacts is reached by an incorporation of climate interlinkages that try to evaluate economic market and non market damages of climate change. The coverage of all GHG improves the economic welfare impacts especially for OECD regions as not only the additional options of emissions abatement increase by the inclusion of all greenhouse gases but also diminishes the international permit price. The additional inclusion of sinks improves the welfare impacts in comparison to all other scenarios which leads to higher economic impacts and damages. The conclusion from this analysis is that on the one hand pure economic effects demonstrate positive impacts of the inclusion of sinks but on the other hand positive income effects lead also to higher non market impacts according to the temperature and seal level variations.

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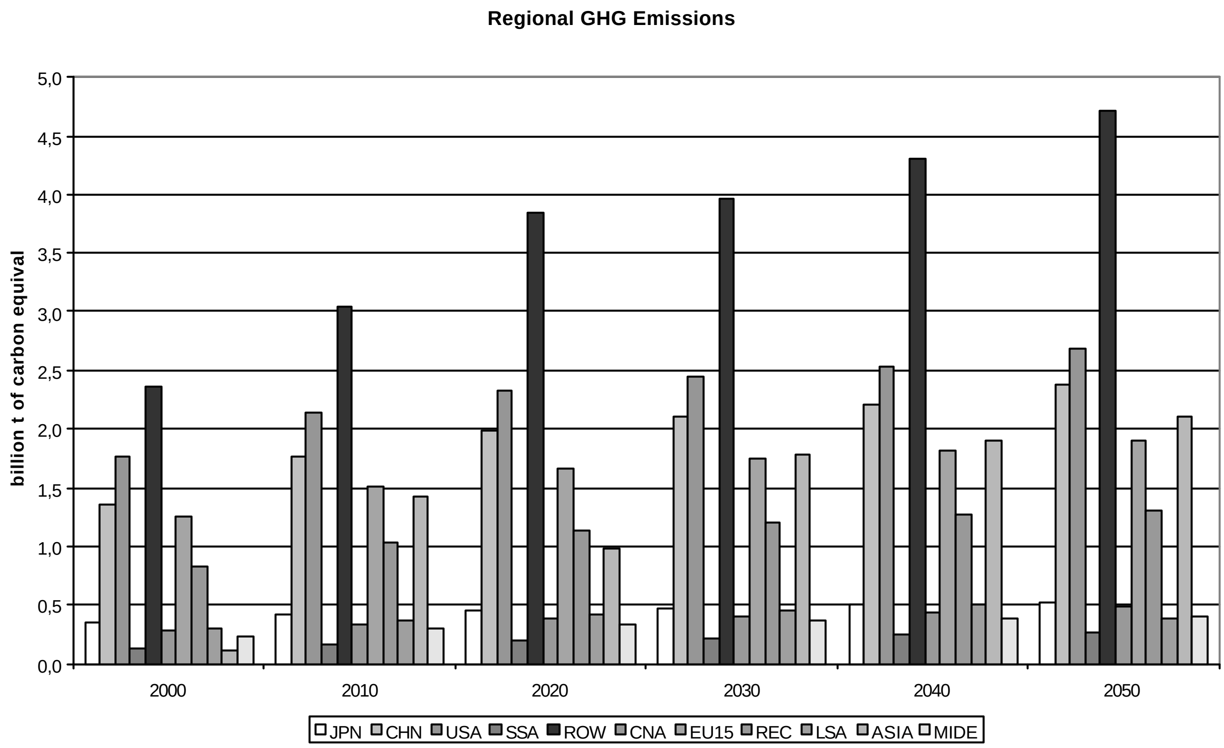

Figure 5: Regional greenhouse (GHG) emissions

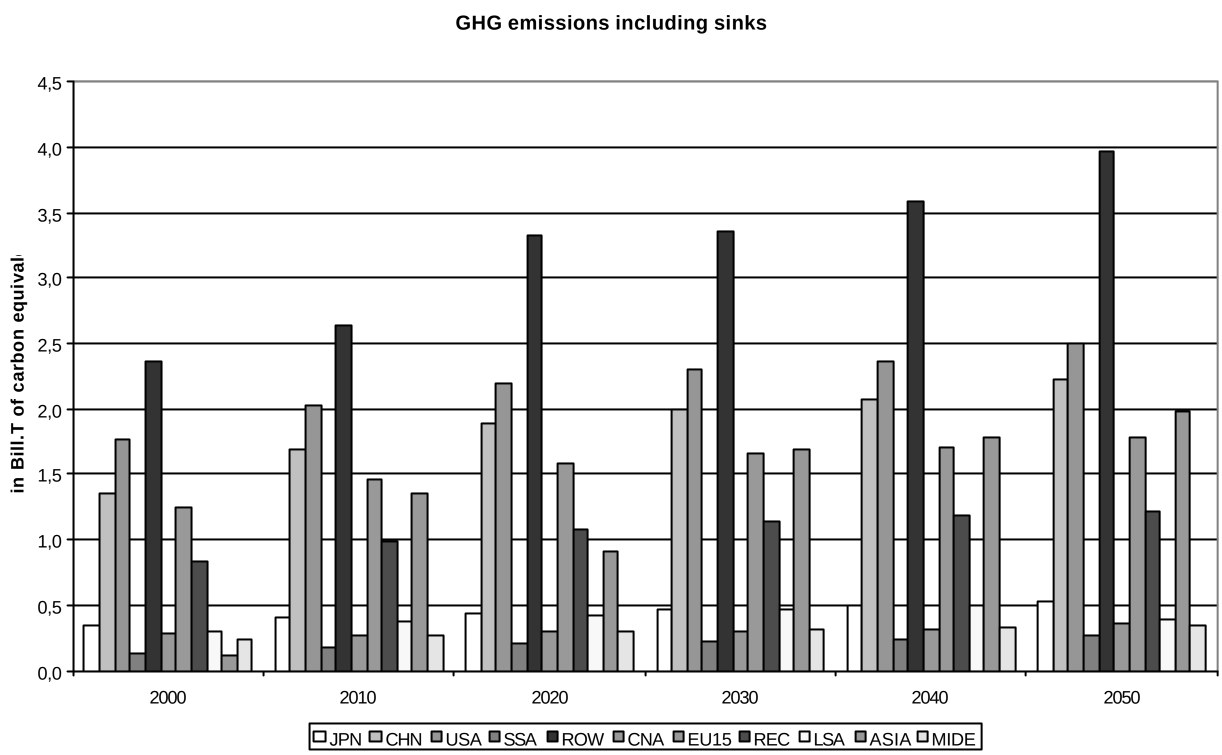

Figure 6: Regional GHG emissions including sinks

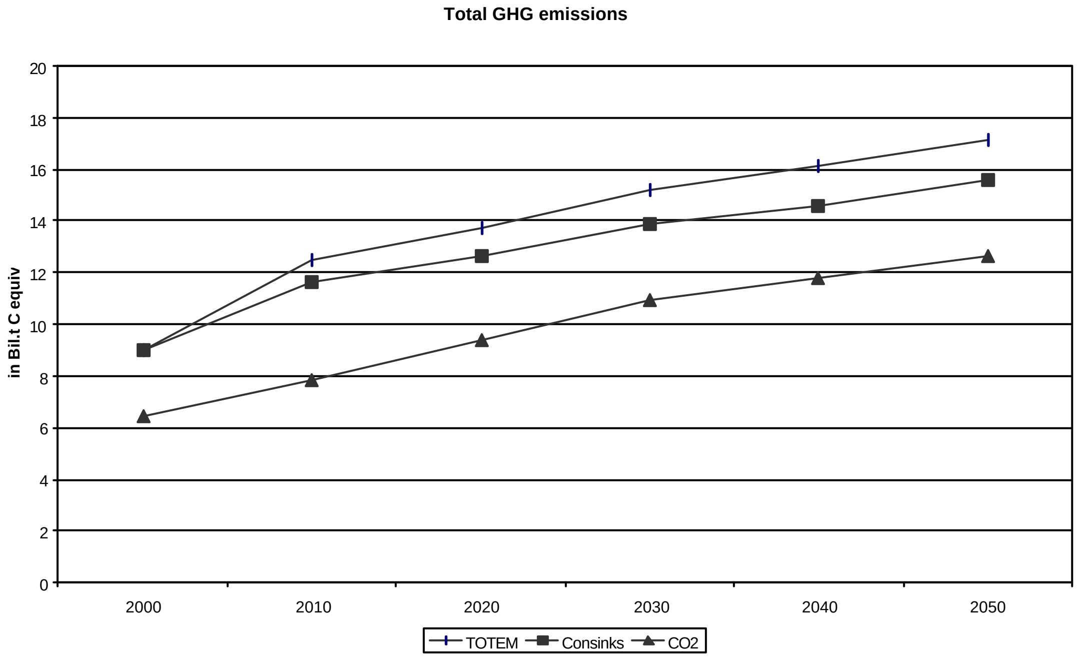

Figure 7: Total CO2 and greenhouse gas emissions with and without the inclusion of sinks

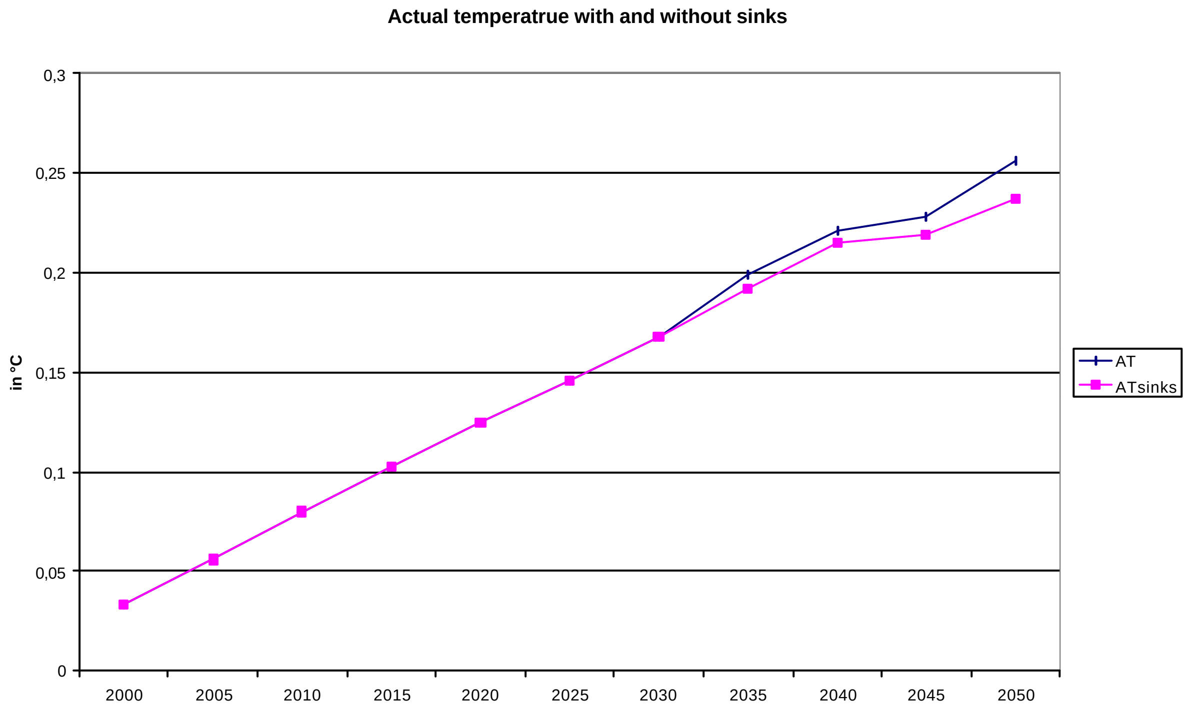

Figure 8: Actual temperature changes with and without including sinks

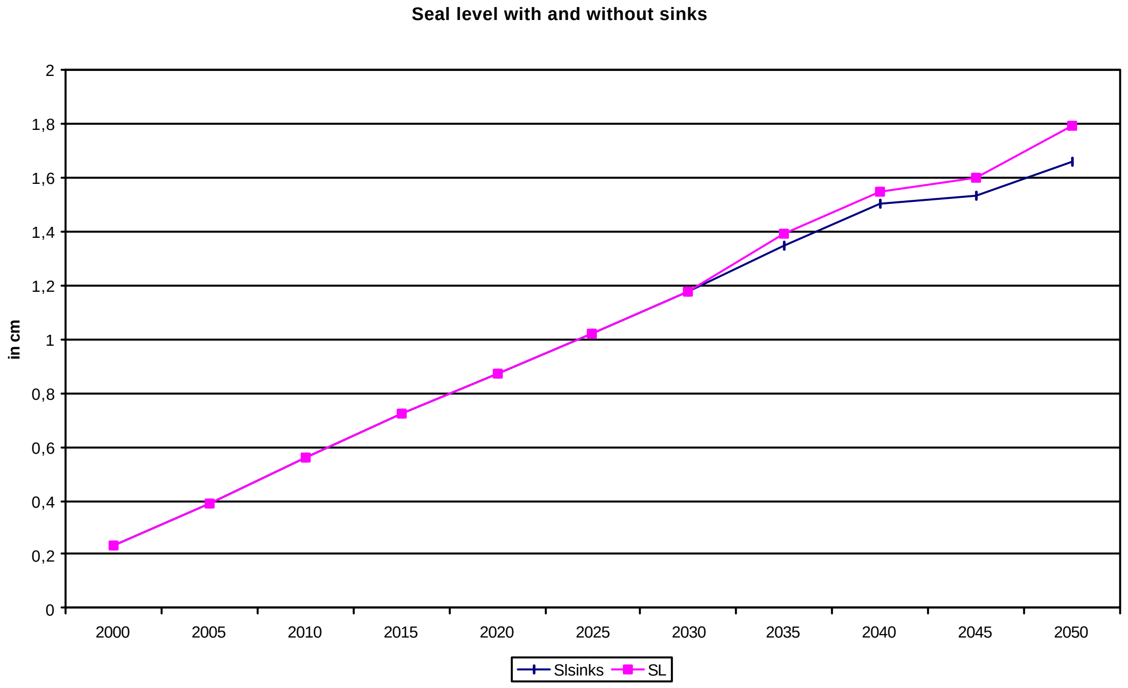

Figure 9: Sea level changes without and without the inclusion of sinks, in cm

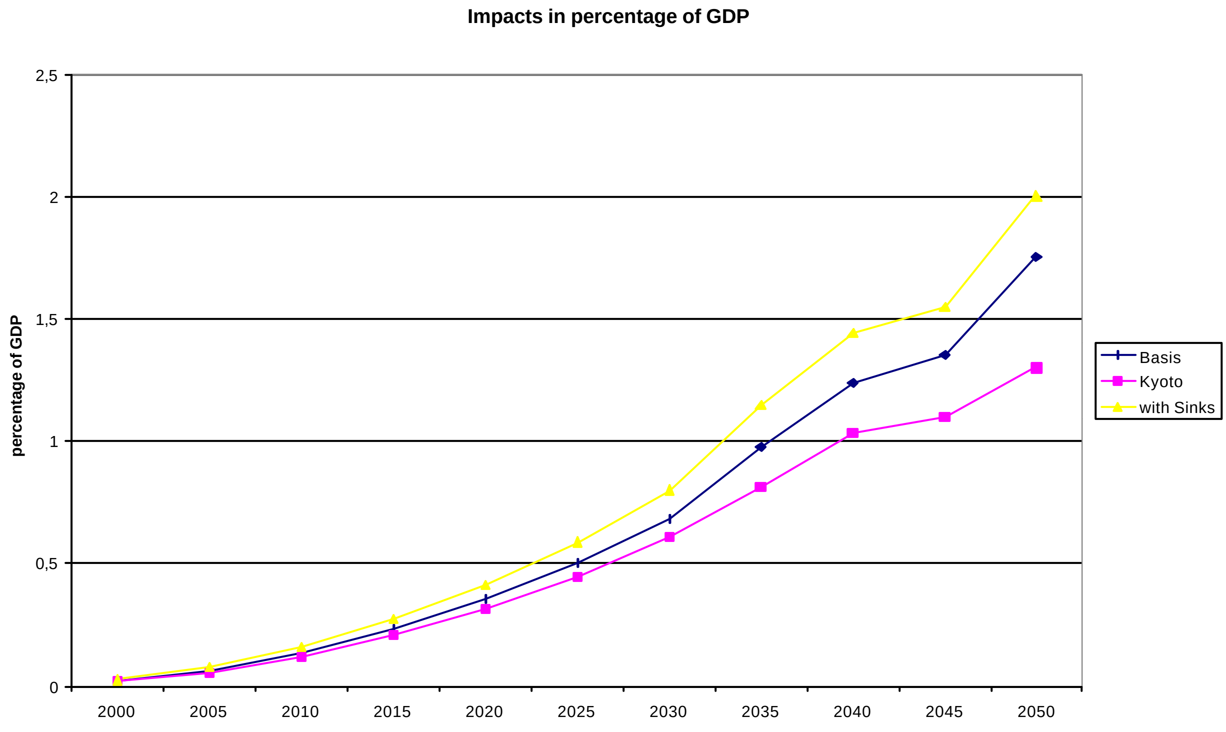

Figure 10: Impacts of climate change in percentage of global GDP